3.2-mJ, 1.5-µm laser power amplifier using an Er,Yb:glass planar waveguide for coherent Doppler LIDAR

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We developed a 1.5 µm eye-safe wavelength high-gain and high-average power laser amplifier using an Er,Yb:glass planar waveguide for coherent Doppler LIDAR. Applying the planar waveguide structure, high-average output power with near single transverse mode was realized. Consequently, high-gain and high-efficient operation were achieved by multi-bounce optical path configuration. Amplifying the pulsed signal light at 1550 nm, the maximum pulse energy of 3.2 mJ was achieved at the repetition rate of 4 kHz. High energy output from this amplifier is expected to extend the measurable range of coherent Doppler LIDAR.

1. Introduction

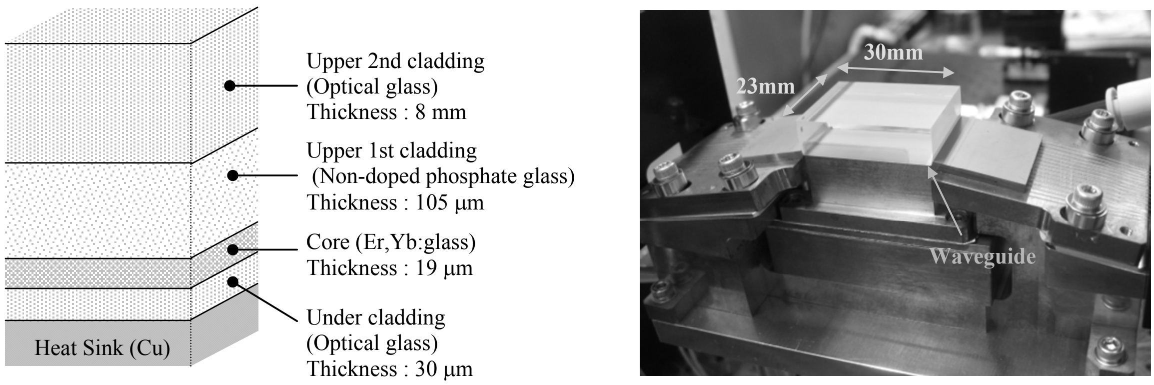
Coherent Doppler LIDAR is a wind profile measurement system using laser light[1]. It has some advantages such as real-time measurement, remote sensing of wind velocity and direction, and so on. The LIDAR can measure the wind velocity even in clear weather condition when conventional weather RADARs cannot measure it. Therefore, it is expected to use in the many applications including the detection of the wake vortex induced by an airplane and clear air turbulence for air traffic safety.

We have been developing coherent Doppler LIDARs using eye-safe 1.5-µm lasers[2, 3]. Also we are now developing an airborne coherent Doppler LIDAR system for detection of clear air turbulence to avoid flight accidents. To realize airborne LIDAR system, high-energy output, eye-safety, and compactness are required for a laser source. The single-pulse maximum-permissible-exposure for human eyes in the 1.5-µm range is much higher than other wavelength. At the wavelength of 1.5 µm, optical fiber components and devices for optical fiber communications are easily available. But, it is difficult for fiber amplifiers to obtain single-frequency high-peak-power pulse output due to the nonlinear effects, especially for Brillouin scattering.

Er,Yb:glass is the most popular laser medium at the wavelength of 1.5 µm and has been studied for a long time[4, 5]. A laser oscillator for a coherent Doppler LIDAR with high-peak-power pulse using the Er,Yb:glass rod had been reported [6]. However, the small emission cross section, low thermal conductivity and low thermal fracture limit of Er,Yb:glass made it difficult for researchers to realize high-average-power laser operation. To realize high-average power operation using Er,Yb:glass laser material, we applied a planar waveguide configuration to the laser material. Planar waveguide laser has many attractive features such as high-efficient operation by high-intensity pumping, high beam quality by mode selectivity of the waveguide, and power scalability along planar direction. Although Er,Yb:glass has low thermal fracture limit, large cooling surface of the planar waveguide structure enables high average power pumping. Multi-bounce optical path configuration provides high-gain amplification in spite of the small stimulated emission cross section of Er,Yb:glass. Nonlinear effects can be suppressed and high beam quality can be achieved by designing the beam size and waveguide structure. Applying the planar waveguide configuration to Er,Yb:glass laser material, we have realized a high-gain and high-average-power laser amplifier at the wavelength of 1.55 µm which can generate over mJ pulse suitable for coherent Doppler LIDAR.

2. Configuration of the amplifier

Fig. 1 shows structure of a double-clad Er,Yb:glass waveguide. Fig. 1(a) shows a sectional image of a planar waveguide, and Fig. 1(b) shows a photograph of the waveguide. Double-clad waveguide is consists of Er,Yb:glass for core, non-doped phosphate glass for inner cladding (upper 1st cladding), and optical glass for outer claddings (under cladding and upper 2nd cladding). The waveguide is bonded on water-cooled copper heat sink using adhesive. The concentrations of the Er,Yb:glass are 0.87-wt % Er_2O_3 and 16.3-wt % Yb_2O_3. The thickness of the core is 19 μm and waveguide area is 23 mm x 30 mm. To obtain a low-order guided-mode propagation of signal light, refractive index of the core is slightly larger than that of the upper 1st cladding by 0.3 %.



(a) Sectional image of a waveguide

(b) Photograph of the Er,Yb:glass planar waveguide

Figure 1. Structure of a double-clad Er,Yb:glass waveguide

Fig. 2 shows configuration of a laser amplifier which has multi-bounce optical path. Two pumping surfaces (left and right side surfaces in Fig. 2) of the waveguide are polished and coated with anti-reflection (AR) coating at 940 nm for pump light. 28 pig-tail 940 nm laser diodes (LD) are used for pumping through two fiber arrays. The maximum pumping power is 312 W.

1550 nm DFB fiber laser is used for signal source and pulsed by acousto-optic modulator (AOM) with the repetition rate of 4 kHz. The output pulse is amplified by a 2-stage optical fiber amplifier. The signal light is focused on the anti-reflection coated area for 1550 nm by a cylindrical lens and coupled to the waveguide. Average power of the input signal light is 60 mW (15 μJ / pulse). Signal light propagates in the waveguide core with guided-mode along the waveguide direction and free space propagation along the planar direction. Multi-bounce optical path configuration is realized by two high-reflection (HR) coatings which are slightly tilted. Input and output signal path are separated by an optical circulator which is composed of a polarization beam splitter and a Faraday rotator.

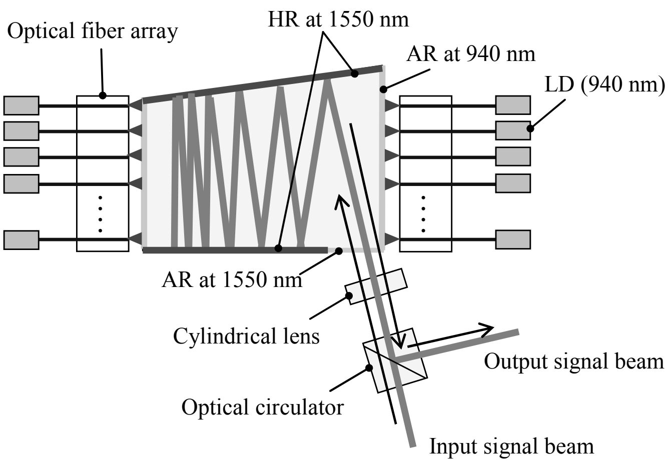


Figure 2. Optical path of the planar waveguide amplifier

We have to suppress amplified spontaneous emission (ASE) because ASE wastes gain in the waveguide. To suppress the ASE, the wavelength of 1550 nm is selected for a signal instead of 1535 nm. Er,Yb:glass has gain peak at the wavelength of 1535 nm, so that the ASE would be generated at the wavelength of 1535 nm. If the wavelength of 1535 nm is used for a signal, it is difficult to distinguish between the signal and ASE and suppress only ASE output. Fig. 3 shows emission cross section of Er,Yb:glass. The emission cross section of 1535 nm is about twice higher than that of 1550 nm. Higher gain of 1535 nm generates ASE and decreases the gain for 1550 nm. To suppress ASE at the wavelength of 1535 nm, we append losses for the ASE wavelength by decreasing the reflectance at 1535 nm of the HR coatings. Fig. 4 shows the calculated amplification gain for 1550 nm and 1535 nm as a function of path length. At the path length of 23 mm which is corresponding to a single path length, the amplification gain of 1550 nm is 66% lower than that of 1535 nm. Amplification gain of ASE can be suppressed by reducing the reflectance at 1535 nm to less than 66%.

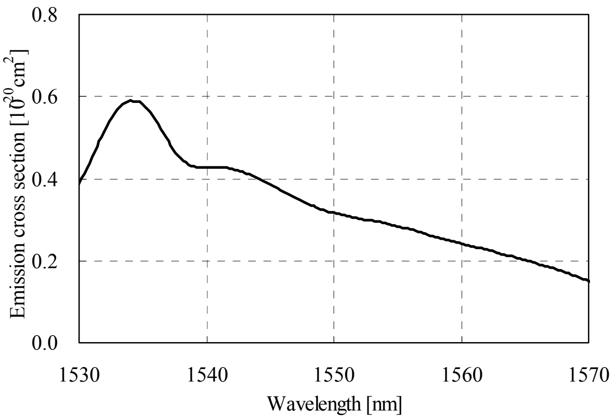


Figure 3. Emission cross section of Er,Yb:glass

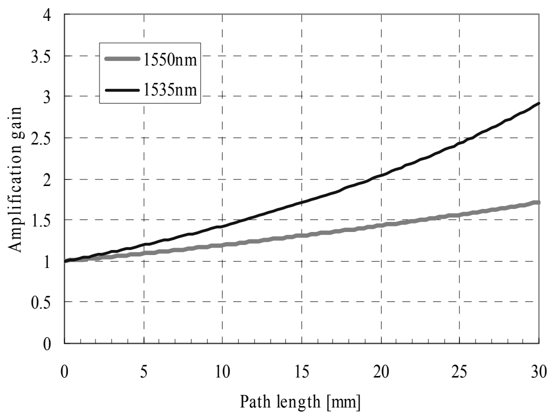
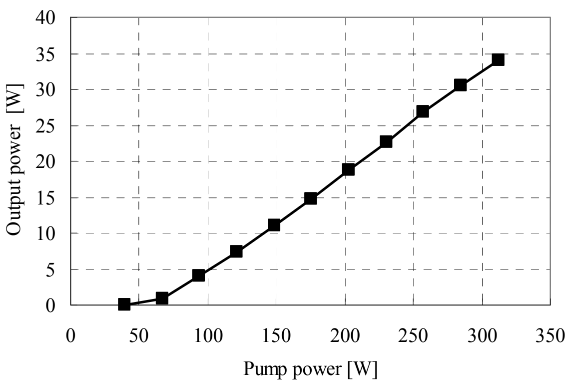


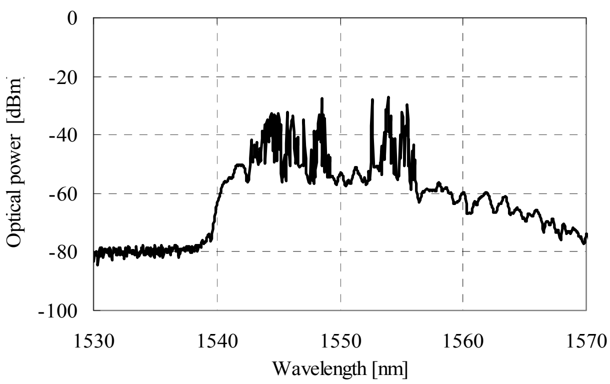
Figure 4. Calculated amplification gain for path length

3. Output characteristics of the amplifier

To evaluate the waveguide characteristics, we measured an ASE output power without a signal light. Fig. 5 shows ASE output characteristics of the Er,Yb:glass waveguide. Fig. 5(a) and (b) show the measurement results of output power and spectrum, respectively. The maximum output power of 34 W at the pump power of 312 W was obtained. ASE occurred mainly at 1548 nm and 1553 nm, and the ASE at 1535nm was suppressed.



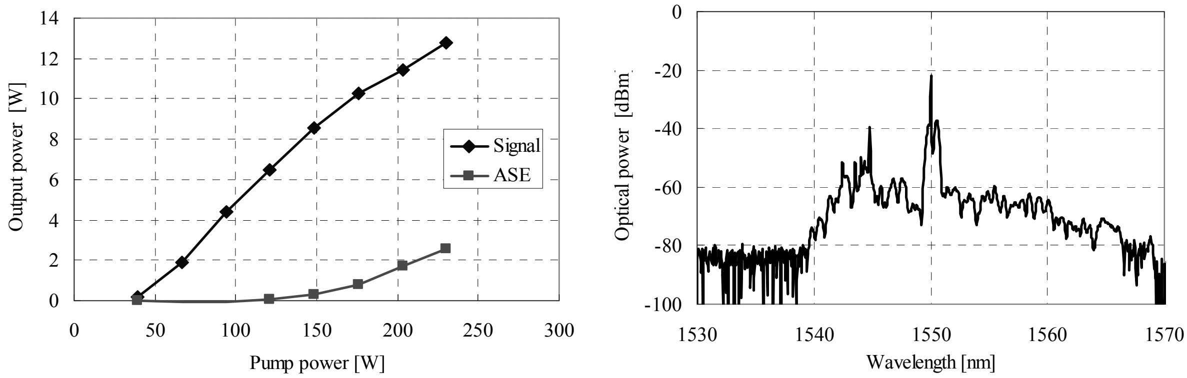
(a) Output power



(b) Spectrum

Figure 5. ASE output characteristics of the Er,Yb:glass waveguide without signal input

We measured amplification characteristics with pulsed signal light. Fig. 6 shows the experimental results of pulsed signal amplification. Fig. 6(a) and (b) show measurement results of output average power and spectrum, respectively. ASE output was separated by using narrow line-width band-pass filter at 1550 nm. The maximum average output power of the amplified signal was 12.8 W (3.2 mJ / pulse) at the pump power of 230 W. ASE was effectively suppressed, except for small peak around 1545 nm. Measured pulse width was 579 ns after amplification, and peak power of the output signal was calculated to be about 5.5 kW. Measured beam quality factor M^2 was 1.0 for horizontal direction and 1.4 for vertical direction.



(a) Output power (b) Spectrum

Figure 6. Amplification characteristics of the Er,Yb:glass waveguide with pulsed signal light

4. Conclusion

We have demonstrated a high-average-power and high-peak-power laser amplifier using an Er,Yb:glass planar waveguide suitable for a coherent Doppler LIDAR. With the pulsed signal operation, the amplified signal average power of 12.8 W was obtained with the amplified gain of more than 23 dB at the repetition rate of 4 kHz. According to our own research, this is the highest average power for Er,Yb:glass laser material.

References

[1] R. M. Hufaker and R. M. Hardesty, "Remote sensing of atmospheric wind velocities using solid-state and CO2 coherent laser systems," Proc. IEEE, 84, pp.181 (1996).

[2] K. Asaka, et al., "1.5-µm eye-safe coherent lidar system for wind velocity measurement," Proc. SPIE, 4153, pp.321 (2001).

[3] S. Kameyama, et al., "Compact all-fiber pulsed coherent Doppler lidar system for wind sensing," Appl. Opt., 46, pp.1953 (2007).

[4] P. Laporta, et al., "Diode-pumped cw bulk Er:Yb:glass laser," Optics Letters. Vol.16, No.24, pp.1952-1954 (1991).

[5] E. Georgion, et al., "High-efficiency and high-output pulse energy performance of a diode-pumped Er:Yb:glass 1.54-µm laser," Applied Physics B 70. pp.755-762 (2000).

[6] T. Yanagisawa, et al., "11-mJ, 15-Hz single-frequency diode-pumped Q-switched Er,Yb:phosphate glass laser," Optics Letters. Vol.26, No.16, pp.1262-1264 (2001).